AGRICULTURAL Science Review

COOPERATIVE STATE RESEARCH SERVICE U.S. DEPARTMENT OF AGRICULTURE VOL. 10, NO. 2

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AGRICULTURAL SCIENCE REVIEW

Second Quarter 1972 Vol. 10 No. 2

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AGRICULTURAL SCIENCE REVIEW is published quarterly by the Cooperative State Research Service, U.S. Department of Agriculture, Washington, D.C. 20250.

ROY L. LOVVORN, Administrator

Review's Editor Retires

This is the first issue of *Agricultural Science Review* which was not personally attended from conception to publication by Ward W. Konkle, the Journal's first and, so far, only editor. Mr. Konkle retired in April after a career devoted to building communication pathways across the no-man's-land between scientists and laymen, and sometimes between scientist and scientist as well. Mr. Konkle had vast respect for the methods and accomplishments of science. At the same time he recognized that the very success of science creates ever more formidable barriers to understanding.

"Of highest priority is the need for better public understanding of science knowledge," he wrote. "Surveys have revealed wide areas of ignorance about modern technological concepts. Such ignorance is detrimental to the public welfare and to the scientific community itself. Much of the burden for correcting this situation rests with scientists themselves. Only when they adapt their language at the right time and in the right way can the myths and misunderstandings surrounding the research laboratory be dispelled.

"Almost equally important is the need to establish a more effective crossfire of disciplines; that is, the interaction of every branch of science with other branches. This interdisciplinary communication depends heavily on the use of a language geared to the premise that every science author is somewhat of a layman for articles in fields other than his own."

Editor Konkle's advice to the scientist-as-writer is so deceptively simple it is easily dismissed as a cliche: "Decide what you want to say and then say it as simply and clearly as you can. There is no better way to get your message across." He presented this message in his teaching and editing with persistence and good humor. Only rarely did a touch of exasperation show through: "Of course the trouble is that some scientists refuse to endure the supposed indignity of clear speech and writing."

Agricultural Science Review will change in some degree with Mr. Konkle's retirement since a magazine inevitably reflects the personality of its editor. But his goal of clear writing will remain a part of the *Review's* creed.

PLANT RESISTANCE TO INSECTS

ERNST HORBER

INSECT-resistant varieties provide an ideal way to control or suppress insect damage to crops. They involve minimum production costs, leave no insecticide residues in food or the environment, harm no pollinating or otherwise beneficial insects, only minimally disturb nature's balance between destructive insects and their natural enemies and are compatible with biological, chemical, cultural and other control methods. Resistance affects insect pests only while they attack plants.

Plant breeders and entomologists, with relatively small budgets, already have developed some insect-resistant varieties of crops.

Breeding resistant crops is neither simple nor quick. The insect-hostplant relationship requires intricate knowledge of the physiology and behavior of insects, morphology, physiology and genetics of plants. Several genes must be combined and their frequency increased to confer the resistance required in the majority of the plant population. Resistance developed to a pest may not be permanent, or may leave the plant unprotected from another pest. With such easily handled crops as tomatoes or wheat, 8 to 10 years may be required to find resistant germ plasm, incorporate genes into commercially acceptable varieties, and to propagate enough seed for commercial use. In the 1920's it took 15 to 20 years from crossing to release of wheat varieties that resisted the Hessian fly (*Mayetiola destructor* Say); in the 1960's, only 8 years. Moapa, an alfalfa variety that resists the spotted alfalfa aphid (*Therioaphis maculata* Buckton) was developed in only 3 years, an unusual accomplishment.

More recently, efforts have turned to multiple pest resistance. Already some 25 vegetables are reported to fend off 35 species of insects. Many of these successes were achieved with relatively modest research budgets and sometimes little knowledge of the nature of resistance and its inheritance.

After resistance has been developed, "biotypes" or races may then attack the crop. Fortunately, it

generally requires several years for such biotypes to develop.

Because of environmental concerns, it is preferable to breed for varietal resistance, even though insecticides considered effective and "safe" are available. A "fireproof building" is preferable to "firefighting." Unfortunately because of too much dependence on insecticides, considerable knowledge and germ plasm, involving resistant varieties adapted to local conditions, may have been lost.

Various approaches to hostplant resistance are available. Beck distinguishes two: (1) the "Painter-approach" which entails subjecting large numbers of plants to intense insect infestation, then selectively breeding the survivors. It requires knowledge of the insect's biology and good collaboration with breeder and geneticist. This approach has been combined with the search for resistance in the same or related species or genera to incorporate favorable characteristics into an agronomically desirable variety. That approach has efficiently found resistant varieties to be developed. It still is the most practical, rapid, and cheapest method. (2) Beck's approach, an "after the fact" study, determines the mode of action of resistance, by comparing characteristics of resistant genetic lines with those of susceptible lines. Such studies should follow the first approach to explain the mechanism of resistance and the mode of inheritance. Other approaches involve long-term studies of physical and chemical plant factors and of insect behavior, development, and reproduction on both resistant and susceptible plants.

Insect-Hostplant Relationship

PAINTER (*20*) divided insect-resistance, as observed in the field, into three categories: (1) nonpreference, rendering the plant unfit or unattractive to inspect pests as food, for oviposition, or shelter; (2) antibiosis, adversely affecting growth, survival or reproduction of the pest; and (3) tolerance, imparting ability to withstand, or to recover from injury, despite supporting a pest population that would severely damage susceptible hosts.

Plant resistance is sometimes equated with antibiosis. However, nonpreference should not be overlooked. Where even brief infestations cause severe damage, as when virus transmission occurs or when vital parts of the plant are severed, nonpreference may be more important than antibiosis. Both antibiosis and nonpreference influence the density of insect populations, whereas tolerance exerts no inhibitory effect on insect multiplication. Tolerant plants, supporting larger infestations with little damage or yield loss, may be even more conducive to population buildup than susceptible varieties. Tolerance has value in preventing the buildup of new biotypes and in maintaining natural predators and parasites. In alfalfa, tolerance maintains forage quality, assures stand establishment and therefore helps overwintering of the new crop. However, varietal resistance of the tolerance type must be supplemented by antibiosis, nonpreference, or by cultural, biological, or chemical control.

The proper balance of the three categories of resistance in the same variety can be achieved and evaluated in pest management programs involving large areas over extended periods.

Phytophagous insects recognize their hostplant through a chain of interdependent conditioned reflexes (*3, 16, 32, 35, 58*). Visual, olfactorial, gustatorial, and tactile stimuli influence oviposition, feeding, and sheltering and, thus, determine the degree of an insect's host specificity.

Olfactorial and gustatorial chemoreceptors in insects discriminate between acceptable and unacceptable plants (*27*). High sensitivity of chemoreceptors to inhibitory stimuli or to lack of feeding-incitants is associated with narrow food specialization. In some insects chemotaxis is highly developed, enabling them to detect biochemical changes in plant tissues during different growth stages. Resistance may be conditioned by the presence or absence of the active material in the right tissue at the right growth stage. Biochemicals responsible for resistance may interfere with an insect's physiological processes or may be toxic or repellent (*3*).

Active materials include attractants, repellents, arrestants, feeding stimulants, and deterrents (*3, 6, 7, 32, 58*). Before a certain attractant, repellent, or insecticidal property is unequivocably attributed to a biochemical, it should be isolated in pure form and its composition, structure, and activity thoroughly determined in resistant and nonresistant cultivars, preferably isogenic lines. Proved adverse properties of a biochemical to insects should also

be evaluated with respect to food value, palatability, and toxicity to higher animals.

Choice for feeding, ovipositing, or sheltering may be determined by such external protective features as thickened epidermis, fibrous cuticle or spiny surface, small cavities or crevices, pubescence, or hairiness. They often are difficult to distinguish from chemical factors.

Major emphasis to induce noninherited resistance has been along the lines of crop management; for example, cultivation and proper use of fertilizers. This applies particularly to control of insects that attack long-lived trees or ornamentals. Because of their long lives, it is difficult to develop inheritable resistance. Also, such controls are effective against some important pests that tend to attack only crops that are in moribund or severely weakened condition.

Factors Affecting Expression of Resistance

SOME plant varieties have maintained high resistance or near immunity, such as grape to the grape phylloxera (*Phylloxera vitifoliae* Fitch), or apple to the woolly apple aphid (*Eriosoma lanigerum* Hausm.) since the 19th century. However, such stock too often is grown exclusively in an area, or is distributed beyond its ecological range where it encounters aggressive biotypes.

Insect populations often develop new, physiologically distinct biotypes. Polyphagous species are generally less subject to biotype formation than monophagous insects because selection pressure to starvation is rarely achieved. The Hessian fly, spotted alfalfa aphid, greenbug (*Schizaphis graminum* Rond.), and rubus aphid (*Amphorophora rubi* Kalt.) show that biotypes have a "lock and key" relationship to individual genes for resistance.

Wheat varieties in Kansas and California remain resistant to the Hessian fly. In Indiana, however, extensive acreage of cultivars carrying H_3 gene for resistance caused the fly population to shift from predominantly race A to race B. Now most wheat cultivars grown in Indiana carry resistance to both races (*14*).

Sources of resistance are available for each of the six races of Hessian fly now known. Other examples of biotypes are nine reported in pea aphid (*Acyrthosiphon pisum* Harris) on legumes, four in rubus aphid (*Amphorophora rubi* Kalt.) on raspberry, and four in the corn leaf aphid (*Rhopalosiphum maidis* Fitch) on sorghum and corn.

Because most aphids are partly parthenogenetic, a single female, capable of feeding on a resistant plant, may build up a new population.

A new biotype of greenbug, "Biotype C," recently has caused losses to sorghum, but sources of resistance to Biotype C have been secured (*12*).

Six biotypes of the spotted alfalfa aphid recently were recognized in western United States. Four were identified during a combination of studies including tests on the parental clones of the resistant alfalfa cultivars Moapa and Washoe, involving biological activity and response to some organophosphate insecticides.

Fewer cases of aggressive biotypes are known among insects than among diseases. Because resistance to insects is more complex, it is apparently more difficult for an insect to be selected in nature for ability to infest a resistance plant than it is for a pathogen.

The only way to keep ahead of new biotypes is to constantly observe behavior of pests on resistant cultivars and incorporate several genetic factors for each category of resistance—antibiosis, nonpreference, and tolerance.

Cultivars combining moderate antibiosis with high tolerance may be ideal. They allow an adequate pest population large enough to maintain predators and parasites and to outbreed new or potentially new biotypes, but not large enough to cause measurable crop loss.

The degree to which a plant is suitable as an insect host can be modified by such environmental factors as light, temperature, moisture, and nutrients. Responses of insects, including olfactory and gustatory stimuli, also are modified by environmental changes. Thus, a variety that exhibits resistance in one locality or environment may be susceptible in another.

The optimum temperature for pea aphid reproduction and survival was several degrees higher on alfalfa plants that appeared susceptible under field conditions than on plants that appeared resistant.

The possibility of low temperature reducing resistance was first noted with the spotted alfalfa aphid. Temperature may affect the insect directly or in-

directly by influencing growth rate of the insect or its hostplant. Wheat cultivars carrying certain genes for resistance to Hessian fly allow a greater infestation in the greenhouse under high temperatures than under lower temperatures in the field. Temperature differences may explain minor fluctuations in resistance in the field. Effects of high temperature appear to be greater in heterozygous plants.

Soil moisture frequently is influential. Plants attacked by insects with sucking mouthparts appear to be particularly influenced by soil moisture. Either an excess or a deficiency may make the plant more susceptible. Such effects often are superimposed on varietal differences.

Plant nutrition through natural soil fertility or artificial fertilizer affects resistance. Each insect species, and often each hostplant species or variety, constitutes a separate problem.

Plant age may influence resistance, older plants being more resistant.

Breeding Insect-Resistant Cultivars

SELECTION and breeding for resistance have come a long way since 1878 when farmers noticed differential grasshopper damage in adjacent crops of corn and sorghum. The first was completely stripped, while the latter was almost entirely avoided by these voracious and supposedly omnivorous insects. For most crops, including even forage grasses, *proveniences and landvarieties* have been replaced by *cultivars*. The recent development of *isogenic lines*, which differ in one single character—for example, resistance to insect or disease—greatly facilitates studies on causes of resistance and their inheritance.

The first step in breeding for resistance is to screen available germ plasm for resistance to a particular pest. Generally, they have been found when adequately researched. Success is generally proportional to the number and diversity of plants available. Efficiency of screening depends largely on successful management of infesting insect population. Techniques are available or may be developed to assess all three categories of resistance and to detect and exploit low as well as high resistance. Adapted lines from the insect-problem area should be considered first because maximum diversity of resistant-related physiology and responsible genes occurs near the center of origin. Frequently resistance to a particular pest is recovered in cultivars or selections from areas where the pest is indigenous. However, natural resistance has occurred in material from areas outside of the natural range of the pest.

Initial screening tests are designed to reject the bulk of the susceptible material. Subsequent screening should exclude escapes and host evasion (*20*). The remaining few lines are retested intensively to determine consistency of resistance and to discard the pseudo-resistant. Studies on the inheritance of resistance may help to identify different genes for resistance. If naturally occurring variation is not sufficient, genes should also be searched for among other species of related hostplants or in artificially induced mutants

Close collaboration between entomologists and plant breeders, and frequently plant pathologists and agronomists, is needed.

Information is needed on genetic variance for resistance in both the host and in the insect, and the consequent interactions between such genotypes and the environmental conditions that affect plant resistance and insect aggressiveness. Recurrent phenotypic selection, a form of mass selection, was especially effective in developing resistance to the spotted alfalfa aphid, pea aphid (*5*), potato leafhoppers, alfalfa weevil (*2*), and European corn borer (*9*) and for development of multiple-pest resistance (*11*). Mass selection conserves genetic diversity, increases frequency of desirable genotypes, develops new genotypes, and enhances success of extracting individual plants that combine attributes needed in future cultivars. It is necessary to recombine numerous parents to initiate the next generation.

Cumulative resistance may be achieved by combining components of resistance and by combining genes for particular component of resistance. Such an accumultaion of resistance factors makes much more difficult natural selection of biotypes able to infest or injure the resistant variety (*21*).

Initial screening based on seedling mortality is especially valuable because it measures the sum of the three resistance categories. Greenhouses and environmentally controlled growth chambers make it possible to maintain environmental conditions for specific selection over extended periods. Seedling resistance thus obtained must subsequently be evaluated under field conditions.

Entomological Techniques and Procedures

NATURAL selection seldom occurs under intense cropping, since it does not assure evolution in favor of cultivars of desirable agronomic or esthetic values. For many insects, however, the outbreaks which occur periodically may be used to select plants showing varying degrees of resistance. These outbreaks have been particularly useful in selecting plants with resistance to the pea aphid and to the spotted alfalfa aphid; also for recurrent selection to develop resistance to the potato leafhopper and to the alfalfa weevil. Areas where infestation and damage are most frequent are valuable for resistance-evaluation nurseries.

Thousands of seedlings can be evaluated rapidly under controlled conditions in greenhouses and growth chambers. Mass rearing is required to attain appropriate infestation levels.

Mass screening of seedlings is valuable because resistant individuals often are a small minority of a generally susceptible population. Environmental conditions must be adjusted to favor either the plants or insects according to the selection pressure required, in addition to maintaining the appropriate infestation level and homogenous distribution of the insects.

Diets of known composition for phytophagous insects offer several obvious advantages. When insect cultures are known and nutrition is reproducible, one can conduct various tests and large-scale screening for resistance. Nutrition and metabolism can be studied by varying chemical and physical characteristics of diets and environmental conditions.

Insects that feed on stored products and omnivorous species are comparatively easy to adapt to laboratory culture. Insects that feed on growing plants are more selective; some choose a single species as their host or feed on a specific tissue or plant organ.

Resistance is usually measured by counting, weighing, or estimating volume of the surviving insect population or estimating damage to plants. Various indirect methods may be used to determine the surviving insect population: skins shed, parasite exit holes, and parasitized insects. Egg counts may suggest nonpreference. Examples of evaluation of plant damage are height, number of leaves, chlorotic spots, area of leaves consumed and borer holes. Most researchers score damage on a 1 (least) to 9 (most) scale.

Inheritance of Resistance to Insects

IDENTIFYING diverse sources of resistance broadens the genetic base of resistance and makes it

TABLE 1.—*Pickleworm on squash; effect of plant resistance on control with insecticides*

Type of squash	Percentage of infested fruits after treatment		
	1 percent lindane	1.75 percent carbaryl	Untreated
Butternut 23			
Resistant	2	2	3
Summer crookneck			
Low resistance	2	10	49
Benring's green tint scallop			
Susceptible	3	13	62
Caserta			
Susceptible	10	20	72

Source: (*4*)

possible to develop isogenic lines which are valuable tools for studying the mechanisms of resistance.

Although remarkable progress has been made in the development and release of insect-resistant germ plasm and cultivars, genetic makeup and mode of inheritance only rarely have been thoroughly analyzed. The usual procedure is to test the F_2- and F_3-segregates and backcross progenies; sometimes diallel crosses are also used when several resistant or susceptible varieties are available. More advanced techniques were used in breeding for resistance to European corn borer, such as test crosses involving marker genes and reciprocal translocations to determine the chromosomes or their arms that bear resistance genes. The mutable system Ac-Ds was applied to study the potential of genes to induce mutations conveying resistance to the corn borer and mutations conveying resistance to stalk rot disease in otherwise susceptible lines (*9*).

Resistance to the Hessian fly has been the most thoroughly analyzed to determine the different genes involved and what each contributed (*8*). Five pairs of dominant and partially dominant genes and possibly five additional recessive factors are being used in breeding for fly resistance.

Resistance to the cereal leaf beetle (*Oulema melanopus* L.) in wheat is a function of pubescence on the leaves. Analyses of data on F_1, F_2, and backcross progenies from crosses between glabrous and pubescent wheat varieties have shown pubescence to be quantitatively inherited (*25*).

Inheritance of resistance to first brood European corn borer in corn inbred lines was reported (*23*) as three pairs of genes with partial phenotypic dominance of susceptibility in the cross M 14 (S) x MS 1 (R). One or two pairs were responsible in the cross B 14 (S) x N 32 (R), and a single dominant gene, in WF 9 (S) x gl 7 V 17 (R). Most genetic variance is additive although a portion is dominant (*26*). Inheritance of resistance to the second brood is still unknown although data from 45 diallel crosses among 10 inbred lines indicate that resistance is transmitted in hybrid combinations (*9, 19*).

Potato leafhopper resistance in alfalfa is correlated with pubescence but there is evidence of heritable resistance also in glabrous plants. Resistance appeared dominant to susceptibility to leafhopper yellowing, but number of genes involved could not be determined.

Hostplant Resistance in Pest Management

HOSTPLANT resistance was historically established in areas and crops where this was the only possible specific plant protection. *Grape Phylloxera* in Europe in the 1870's is an example. Resistant varieties in wheat against Hessian fly or wheat stem sawfly, *Cephus cinctus,* are later examples. In other crops, resistance only recently has become either a supplement or a substitute for other pest control methods. Resistant varieties may improve the effectiveness of insecticides and make it possible to omit or reduce treatments, and thus escape or lessen undesirable residues or side effects.

Continuous use of relatively large amounts of pesticides over large cotton acreages has left residues at levels sometimes phytotoxic to the crop. These residues are carried to other areas, streams, and lakes. This results in a vicious cycle: The insect pests become increasingly harder to kill. Eventually there is a resurgence of the target pests and outbreaks of secondary pests. In an effort to interrupt this treadmill, major funds are being directed by various agencies and foundations toward cotton including development of resistant varieties.

An important goal in each pest management program is to establish economic injury levels for local areas and conditions. Acceptable injury is sometimes high, particularly when the crop is vigorously developing. Breeders should maintain or achieve high tolerance in newly developed cultivars. Highly tolerant varieties may be regarded as defensive strategy against the development of new, more aggressive biotypes. The insect population may reach densities high enough to allow outbreeding of the population, avoiding new biotypes, without economic injury. On the other hand, varieties bred for antibiosis or nonpreference-type of resistance when they monopolize much of the acreage create selection pressure which screens the population for the most aggressive biotypes.

The significance of hostplant tolerance in pest management is that it allows the hostplant to support subeconomic levels of the pest species while supporting the pest's natural enemies. Low densities of the pest species may be pivotal reserve food supply for beneficial organisms needed later in the growth

period in the same or neighboring crops. The higher the economic injury level a variety has, the more numerous are insects it can tolerate and the longer it can wait for natural enemies to be effective.

Neighboring crops, too, may benefit. Varieties of alfalfa tolerant of pea aphids attract and maintain high populations of ladybeetles and syrphid fly larvae, which peak early and then move on to protect nearby crops. Also after each alfalfa cutting, predators and parasites are forced to forage in neighboring crops, for example, sorghum infested with greenbugs.

Farmers should be educated to accept some damage to tolerant varieties during an outbreak. The damage is still much less than on a susceptible variety. Producers of fruit and vegetables with an economic injury threshold near zero may have to resort to specific insecticides, but in reduced amounts.

In varieties of squash, the percentage of infested fruits decreases as the degree of resistance to pickleworm increases. This is true in both treated and untreated plots, but treatment is advantageous (*4,* and table 1) only for susceptible and moderately resistant varieties.

Even low to moderate resistance may allow treatments to be omitted or to be initiated later or stopped earlier in the season, thus protecting natural enemies and reducing residues on fruits and in the soil.

Another example of beneficial effect of moderate resistance was shown by comparing moderately tolerant alfalfa varieties Team and Weevlchek with Cherokee, which is susceptible to alfalfa weevil (table 2). The moderately tolerant varieties made it possible to delay spraying and to omit one treatment (table 3).

Advantages to producing several moderately resistant varieties instead of one highly resistant one include: (1) moderately resistant germ plasma occurs more frequently than near-immunity in widely diverse germ plasm; (2) greater diversity in the gene pool allows one to adapt new varieties to local agronomic or ecologic conditions; (3) varieties may be changed more frequently; and (4) monoculture and monopoly of one single variety, which a new, aggressive biotype might destroy, can be avoided.

Value of Hostplant Resistance

It is difficult to estimate the value of insect-resistant cultivars because insects damage susceptible crops in many ways and the extent of damage varies widely. Losses from the *grape Phylloxera* in France in 1888 were estimated at 10 billion francs ($2 billion).

Painter estimated that resistant Pawnee wheat yielded about 14 bushels per acre more under heavy Hessian fly attack than susceptible Tenmarq. Gallun's (*8*) survey indicated that the United States grew 8½ million acres of wheat resistant to the Hessian fly in 1969. One cannot assume a 14-bushel-

TABLE 2.—*Alfalfa weevil damage to resistant and susceptible alfalfa varieties*

Variety	Larvae April 21	Alfalfa height April 29	Weevil damage May 5
	Number	*Inches*	*Percent*
Team [a]	675. 0	16. 3	41. 7
Weevlchek [a]	822. 0	13. 0	70. 0
Cherokee [b]	511. 7	12. 0	97. 7

[a] Resistant.
[b] Susceptible.
Team was developed by USDA, N.C., Md., and Va.
Cherokee was developed by Farmers Forage Research.

Source: Unpublished data by permission of W.V. Campbell, North Carolina State University.

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TABLE 3.—*Control obtained by using weevil resistant alfalfa and insecticide*

Variety and chemical	Alfalfa per acre	Weevil damage
Cherokee [a]	*Pounds*	*Percent*
Methoxychlor (2x)	1.5	8.3
Malathion+methoxychlor (2x)	1.5	8.3
Check	–	90.0
Team [b]		
Methoxychlor (1x)	1.5	11.7
Malathion+methoxychlor (1x)	1.5	10.0
Check	–	48.3

[a] Susceptible.
[b] Resistant.

Source: Unpublished data by permission of W. V. Campbell, North Carolina State University.

per-acre increase for all those acres, however, because not all the acreage would have been heavily infested.

Luginbill (*19*) estimated that using resistant spring wheat, Rescue, on Montana's sawfly-infested acreage in 1948 reduced damage approximately $4 million. After that, sawfly populations and wheat losses were reduced to a minimum in all areas where Rescue was grown. The 1 bushel of seed obtained in 1944 from Canada saved Montana farmers at least $40 million in 10 years. Savings to Canadian farmers were many times more.

The contribution of resistance to European corn borer control is difficult to assess because seed companies do not disclose the pedigree of commercial hybrids and the number of resistant inbred lines involved. In 1949, when all known control practices (including chlorinated hydrocarbon insecticides) were in effect, but resistant hybrids were not generally used, loss due to the European corn borer was $350 million. In the 1960's when resistant hybrids were used on 30 million acres, annual losses averaged about $10 million.

Dicke (*24*) reported that hybrids resistant to corn borer reduced the loss at least 20 bushels per acre when borer infestation was heavy. A fourth of that loss on the 30 million acres of resistant corn grown in 1962 would be $150 million in savings. In addition to reducing crop loss, growing resistant corn effectively reduced or suppressed borer populations 50 to 60 percent, thus reducing losses of subsequent crops.

The corn earworm causes an estimated annual loss to sweet corn growers in the United States of more than $12 million even when insecticides are applied. The estimated cost of chemical sprays and the value of corn forage lost by contamination with chemical residues brings total estimated savings from resistant hybrids to more than $17 million annually. Damage to dent corn in the United States has been estimated at $170 million a year. Much of that loss could be prevented by developing and growing resistant hybrids (*19*).

Luginbill (*19*) gave $35 million as a conservative estimate of annual savings to growers using spotted alfalfa aphid-resistant alfalfa cultivars. Resistance helps establish and maintain stands, assures both higher quality and yield of forage, and lower insect and disease control costs. Resistant cultivars became well established while susceptible entries were killed (*28, 29, 53, 54*). Infestations that killed mature stands of susceptible entries did not kill resistant entries. Where the spotted alfalfa aphid occurred after the last cutting, winter survival paralleled resistance scores recorded the previous fall (*5*). Where pea

aphids damaged susceptible cultivars, resistant entries produced two to three times more forage (*22, 30*). Average percentage increases in forage yields for resistant over susceptible plants were 211, 188, 107, and 114 percent for the first, second, third and fourth cuts, respectively. These resistant selections maintained a 78 percent increase over susceptible plants in the first cutting the following year (*13*). Under epidemic infestations of spotted alfalfa aphids, resistant cultivars yielded three to four times more than susceptible ones. In 15- to 80-acre fields foliage damage by the spotted alfalfa aphid was 15 to 22 times greater on susceptible than on resistant cultivars (*1*).

Effect of Resistance on Feeding Value

APPREHENSION has been expressed regarding potentially harmful side effects of insect-resistant varieties on the nutritive value of feed. Tolerance is less suspect than antibiosis or nonpreference. However, reactions of man or domesticated animals should not be directly inferred from the effects of resistant varieties on insects.

Hostplant resistance in annual crops lasts a relatively short time. Chemical substances causing resistance are biodegradable, selective agents directed mostly towards mechanical and physiological injuries. Resistance is sometimes localized in some tissues or plant organs and absent in others. Sometimes the chemicals are biologically active only for a short time at certain developmental stages.

Protein, carotene, and digestible dry matter were similar in susceptible alfalfa varieties and those resistant to the pea aphid and spotted alfalfa aphid (*15, 17, 36*). Likewise, chemical components of resistant "Team" alfalfa were similar to those in susceptible varieties. Neither digestibility coefficients nor performance of yearling Holsteins differed significantly when fed resistant or susceptible varieties (*2*).

Quality and nutritive value as feed is improved by hostplant resistance because less protein, carotene, and vitamin A are lost from resistant than from susceptible varieties. Protein yields of resistant Kanza under attack by the pea aphid were almost double, and carotene yields triple those of the susceptible cultivars, Buffalo, Ranger, and Vernal (*31*). On the other hand, Loper (*18*) reported higher coumestrol content in aphid-susceptible Vernal than in resistant Moapa and Washoe cultivars when all were subjected to aphids.

Price of Hostplant Resistance

SUCCESSFUL development of hostplant resistance to supplant and supplement chemical control requires continuous, vigorous long-range programs, the benefits of which may not be reaped for 10 or more years. Relatively modest budgets have demonstrated successful hostplant resistance. Cost of developing Moapa alfalfa resistant to the spotted alfalfa aphid was reported as less than $30,000 (*10*).

Luginbill (*19*) estimated the total cost of research by Federal, State, and private agencies on resistance to four insect pests at $9.3 million. The professional man-years required were 115 for the Hessian fly, 92 for the sawfly, 119 for the alfalfa aphid, and 136 for the European corn borer. Savings to farmers, which pass to consumers in lower food prices, are estimated at $308 million a year. Assuming that a variety or inbred line will be grown successfully for about 10 years, the annual return for each dollar invested in research and development of hostplant resistance was $300. This does not include the bonus that is likely from effects on subsequent crops of eradicating or suppressing insect pests, or savings from eliminating chemicals and their residues.

Increased funds will be needed for future programs to screen for resistance to diseases, insects, and nematodes among such diverse crops as cereals, forage legumes, fiber crops, tropical food crops, shade trees, vegetables and others. Needed for the job are major investments for modern greenhouses and growth chambers and funds to maintain them. To meet the increased demand for basic information on the mechanism of resistance, such expensive equipment as scanning electron microscopes, gas chromatographs, spectrophotometers, instruments for radioactive tracer technique, and computers must be made available. Desirable instrumentation should be expanded as hostplant resistance is recognized as an ideal area for interdisciplinary research.

Traditionally, hostplant resistance has been attempted only against one insect species at a time. Stepped-up screening procedures should be able to screen for multiple resistance simultaneously in several crops against many insect pests, diseases,

and nematodes.

Although resistance breeding requires a long-range program and teams of well-trained workers and technicians, it does not necessarily follow that breeding for resistance is less flexible than developing chemical controls, or that it cannot easily adjust to suddenly changing situations caused by newly imported pests. The Hessian fly, the European corn borer, the cereal leaf beetle and the spotted alfalfa aphid are all imported pests to which resistant varieties have been successfully produced in reasonably short time.

For a long time, all inputs in hostplant resistance came from Federal, State, and a few private organizations. The public agencies met barriers against long-term studies and development programs. Our "publish or perish" evaluation system also favors short-term projects that give "salami-sliced" publications in rapid succession. A further handicap is the lack of properly trained technicians because graduate students cannot remain on long-term projects. Technicians could do the tedious routine work of screening literally thousands of entries in fields, greenhouses, and growth chambers. A well-trained technical staff also would take better care of such expensive items as growth chambers and continuous mass rearing of insects, with fewer personnel turnovers and interruptions for on-the-job training.

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THE AGRICULTURAL EXPERIMENT STATION
An Institutional Development Perspective

MELVIN G. BLASE AND ARNOLD PAULSEN

THE experiment stations are unusual among research organizations because of their rich tradition as problem-solving, service-oriented research units. There is little doubt that they could develop the capacity to research new problems such as pollution, rural economic development, population distribution shifts and consumerism. A purely objective analysis of the structure and function of public institutions and their relationship to society in general may be useful for increasing the adaptation potential of experiment stations as their directors and department heads face important management decisions relative to these newly emerging problems.

THE MODEL

EVERY public institution is a "system." Each has several components that interact as raw resources are transformed into products. Performing this mission justifies its existence. The goal of a research station is progress, and to achieve this goal it must generate information. All the station's components relate and contribute to performing the station's mission of progress for society. Each institution and each part of an institution respond in a special or predictable manner to stimuli and pressures, and thus, each institution seems to have a unique humanlike personality.

One model of a public institution such as a research station, reflecting some economists' views of an institution, depicts two successive stages of production (fig. 1).[1] First, flow and stock resources are combined into seven intermediate products, which are in turn transformed into three final outputs. In research stations, these three outputs are information, influence, and investment in future capacity. In the long run, only information outputs of research institutions can justify their use of public resources. This information output must make enough net positive change that leaders widely recognize the greater achievement of social objectives made possible as a result. Only by recognizing the return on past investments and expecting a very handsome future return on present ones is society likely to be interested in investments to expand the capacity of research institutions.

This new institutional capacity is somewhat like retained corporate earnings or internally generated capital. Given society's approval, institutional capacity can be internally produced and retained or accumulated by research stations for future use. Even though capacity and the other category of output, influence, are of little direct value to society, a research organization values all three final outputs for its institutional security and survival. Each institution also contains a number of crucial internal and external feedback loops for signal giving and evaluation, which obviously are vital to operating and developing a research station. Perhaps the most important is the feedback from society to the station concerning the value or desirability of its products.

SYSTEM OUTPUTS

INSTITUTIONAL development is concerned with improving the absolute and relative size as well as the competitive position of the institution. The value of the information released determines the worthiness of a research station's contribution in the long run, but does not necessarily determine its survival and growth in the short run. The quantity and mixture of the two other final outputs—influence and capacity—have much to do with the survival and growth of a research station.

[1] R. W. Jones and M. G. Blase, "Toward a General Theory of Technical Assistance." Unpublished manuscript submitted to USAID under the CIC–AID Rural Development Research Project, 1968.

Current Services

THE current services portion of the output in an experiment station is the information it generates and releases—its most normal and visible output. It includes research papers, reports, bulletins, press releases, questions answered, and consultation given. These packages of information flow through delivery systems to users, and if applied, affect the beneficiaries. All productive research is similar in that it contributes to society by providing new understanding that widens the range of choice, increases the options, or reduces resource restraints. Society accomplishes many of its goals through research. Other actions and investments also can accomplish social goals, but not by generating information.

Institutional Reinvestment

THE second category of final outputs is the result of "plowback." Reinvestment recycles some of the output of the resources used up and tries to retain or fix some of the product within the institution itself and, thus, expand subsequent production capacity. This is not free; it requires resources. The cost of reinvestment can be reckoned in terms of reduced current services, but reinvestment results in accretionary growth of the station's stock of resources. Most institutions, research stations included, do not know exactly how much they lose or gain in capacity to produce each year. This capacity consists of stock resources of physical and human capital which also diminish with use, nonuse, and time.

Some investment in intellectual capital and physical facilities is needed each year just to replace that lost by normal attrition and depreciation of existing stock. Only that investment which exceeds that needed to maintain the stock can expand the institution's future capacity. Reinvestment takes such forms as "brushing up" old skills or learning new skills by staff members, reorganization of administrative structures, restocking and updating the library and the laboratories, and even reconsideration of the institution's "doctrine." Program review and planning are investments also.

Influence

INFLUENCE is closely related to current services and investments in future capacity. It results from the incidental or deliberate effort of an institution

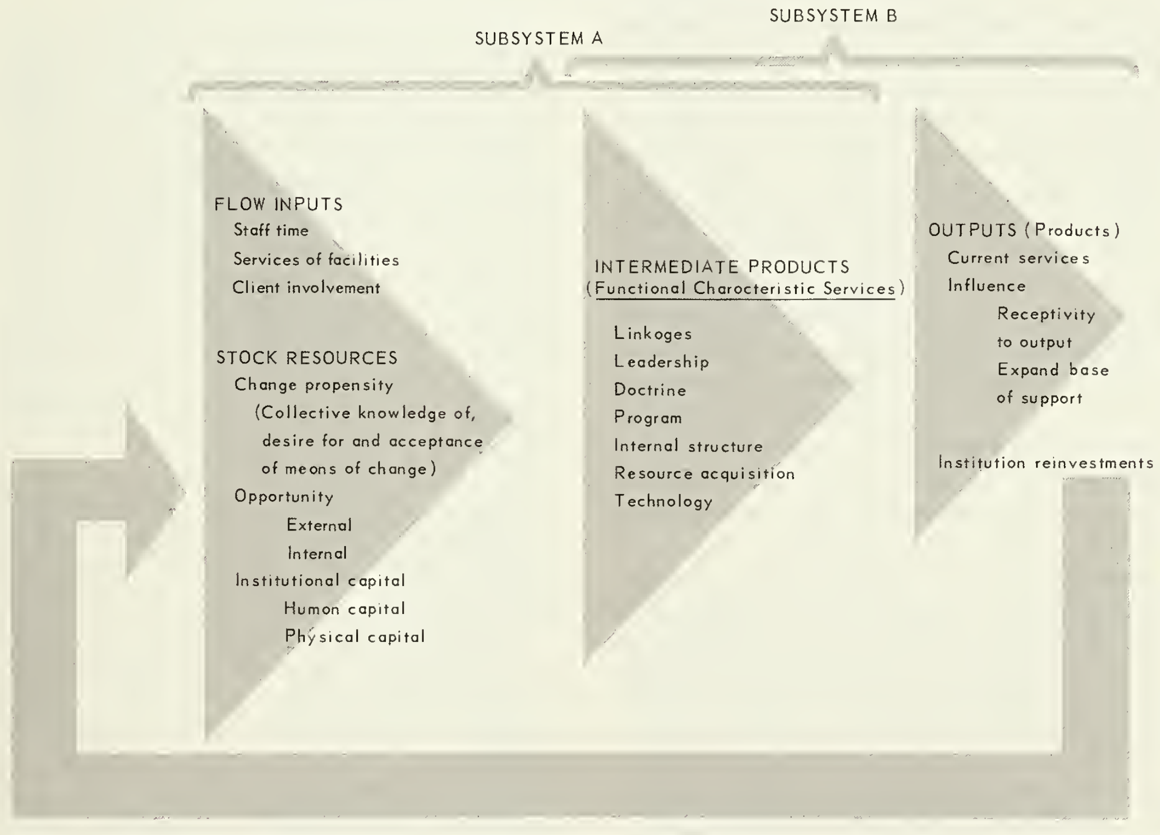
to improve its external relationships or image among the social and political opinion leaders. By influence, the institution hopes to (a) insure its own survival and increase its chance to obtain support and (b) develop a greater appreciation for its current services among its beneficiaries or, in the case of experiment stations, promote faster and more eager acceptance among users for its information outputs. To have influence requires external relationships, and relationships require time. Influence uses resources that might have been used to produce information or expand capacity. If a station is viewed favorably by those who make social and political opinion, they will lobby for the institution's budget.

INTERMEDIATE PRODUCTS

INTERMEDIATE products are for internal use; they usually are not valued *per se* by the fund supplier. They are, however, indispensable to the institution in producing final outputs, and each research institution must produce its own intermediate products. They apparently must be home-produced and cannot be bought, because each institution has unique requirements for linkages, leadership, doctrine, internal structure, program, resource acquisition capability, and technology.[2] Production

[2] Milton Esman, "Some Issues in Institution Building Theory." A paper presented at Regional Conference on Institution Building, Utah State University, Logan, August 1970.

Fig. 1 -- SYSTEMS MODEL OF INSTITUTION PERFORMANCE AND DEVELOPMENT



of these intermediate products consumes resources. Each intermediate product, or service, must be further processed and combined with others before final outputs are obtained. If only intermediate products are produced, no information can be released and no benefits from the institution can flow into the larger society.

Linkage Services

LINKAGES are contacts and relationships with outside institutions and individuals that are formulated and cherished by most successful research stations; yet they are merely intermediate products or services. They are not an end, but the primary means whereby the final product of good will, reputation, or influence of the institution within the larger society has impact. Linkages are and must be two-way streets. The institution receives signals through its linkages with the society. It also sends signals to the society, and this is how the people learn of the capacity, nature, and value of current and future services available from the institution.

But the institution cannot influence without being influenced. Feedback information must be received through linkages for them to convey the message of the institution to society. Society must be aware of and receptive to the information before it can favorably consider it and use it. The research station must know the goals of the society to select high priority problems to research. The intermediate product of linkage produces the contacts, the relationships, and the channels of two-way information flow. To build, maintain, and revise these over time requires resources that have an opportunity cost; that is, they could be used for other valuable intermediate or final products. Hence, some resources of agricultural experiment stations are now being consumed, and justifiably so, in developing and maintaining linkages, although appropriations are not made specifically for that purpose.

Research stations must carefully decide, however, which of the old linkages they should continue and what new linkages they should build. Should they permit relationships with general farm organizations and commodity groups to dominate? Can research stations afford the time and risk of building relationships with community development councils, local governments, consumer groups, and poverty groups? If there are no linkages with these potential users, beneficiary groups, or fund suppliers, there will be no influence from these groups on the program. If no influence is permitted through these linkages, such groups will not likely be receptive to or support the institution's budget. At a time of changing research needs and stagnant or falling budgets, research stations would be well advised to study carefully their past choice of linkages. Have incorrect or too narrow definitions of client groups been used in the past?

Leadership

LEADERSHIP of an institution is vital and yet is not *per se* a final, socially usable product. Leadership transmits much information within the institution and between the institution and client groups. For example, price signals and information on demands of client groups and supply of information from competing organizations are transmitted to the staff from an institution's leadership. It also transmits current information available from the institution and possible future available services to users, beneficiaries, and fund suppliers.

Leadership must perceive social goals and transmit these demands to scientists. Without the signals gathered and transmitted by the leaders, scientists cannot efficiently propose alternative uses for resources. Leadership must appraise the station's program, element by element, and select proposal by proposal those contributing most toward meeting the needs of client groups. Leadership also must mobilize and focus a productive combination of staff, facilities, and technologies to produce effectively (a) that combination of intermediate products most conducive to producing high priority final products, and (b) the best mix of final products possible in light of society's demands.

Leaders must possess attributes that will win recognition and legitimation, both inside and outside the institution. During program realignment, leaders frequently are "caught in the middle" between staff and client groups. Thus, leaders must be able to give reasons to both staff and clients, accept criticism, and imaginatively use limited means such as reward systems to reallocate resources and alter programs. Externally, leadership must maintain linkages with old client groups while building or expanding relationships with client groups not previously served, but for whom the program is expanding its service.

Leadership must be able to identify with and understand the goals of groups of various types. Capable leaders are critically important if a station is to build and maintain the breadth of influence required to serve several groups of users, affect the welfare of beneficiary groups, and obtain funds from several Federal, State, and private sources.

Doctrine

DOCTRINE provides the basic character of an institution and helps to clarify and express its philosophical framework, including identification and weighing of basic institution goals, and delimiting the range of means by which the research station will operate. Doctrine is reflected in reputation and in operating style. Clear and consistent doctrine helps the institution explain and maintain its reputation and style, both internally among staff and externally among client groups.

Traditionally, the doctrine of the land-grant system has been service in increasing agricultural output. This doctrine, however, is coming under attack more and more. Two very different doctrines are warring to replace the old doctrine. One is a science-oriented doctrine that focuses on basic or theoretical analysis for science and professional ends. The other, a social service doctrine, is "people-oriented," and asserts that social goals should direct research programs. The people-oriented doctrine charges that agricultural research stations with the traditional doctrine are too often mere tools of well-capitalized, commercial farmers. The science doctrine asserts that it is indirectly service-oriented. However, only knowledge can and must be sought, and then if found, service to society can be planned or will follow automatically. In the science doctrine, the quality of research program is indicated by the prestige of staff members and stations among fellow intellectuals. The relevant measure of research impact under the science doctrine is publication, not practical application and adoption. Publication and literature citation are measures of output which justify a station under the science doctrine.

Experiment station personnel are currently spending time, hence resources, to produce and extend doctrine, to revive old doctrine, and to defend and attack doctrine. Doctrine, however, is only an intermediate product in institutional development, and only after it is formulated—and the sharp debate indicates the reevaluation of doctrine has not yet been completed—can doctrine contribute effectively to the final output of research stations.

Program

PROGRAM expresses the underlying doctrine. Doctrine by itself is sterile. Current resource allocation by problem areas constitutes the essence of a research station's program and program plan. Of course, only the executed program produces information, but considerable resources can be used in reprograming a station; that is, in review and self study for identifying and evaluating alternatives, making a plan, and carrying it out. Programing represents the allocation of resources among projects or production processes by units of time to produce the selected level and mixture of final products. A multiyear program plan is a very valuable intermediate product of a dynamic developing institution. But it is not free.

Internal Structure

INTERNAL structure is the official organizational chart—and more. Clearly, the chart is the most visible reflection of both program and doctrine. In addition there may be a hidden or unofficial internal structure in an institution not written down, but which reflects an unofficial program and underground doctrine. Internal structure reflects the organization of the information production processes at a research station. Research stations are constantly generating new projects, institutes, and task forces which are microinternal structures. Updating the general administrative structure of experiment stations takes place less frequently.

The lack of general administrative structural change in stations may be inhibiting program effectiveness. By internal reorganization, men and equipment are combined into new hierarchies of authority, new communication patterns, and new combinations of technical ability. Reorganizations are both disturbing and stimulating. Internal structure influences the institution's ability to (a) use resources effectively to produce information, and (b) interact effectively among scientists, disciplines, projects, and with outside client groups.

The stability of the internal structure of most colleges of agriculture and agricultural experiment

stations is probably due to the stability of program and doctrine, which in turn are stable because of unchanging audiences or client groups. Marginal changes rather than major ones have characterized past efforts to internally restructure research stations. To reorganize internal structure requires courage, costs time, and competes with current service production. Nevertheless, new internal structure can at times be a valuable intermediate product and lead to great increases in quantity and quality of the final output.

Resource Acquisition

RESOURCE acquisition is the deliberate generation or acquisition of resources or inputs for the organization. Many station directors are very much occupied with this task. They often devote considerable effort to recruit and mobilize professional personnel, obtain legislative appropriations, negotiate grants and contracts, and build and maintain information pools and physical facilities. Yet if the institution is to survive, resources must be acquired to replace those which are used up, retired, lost to competitors, or for other reasons will not be available in the future. If the institution is to grow, resources must be acquired more rapidly than they are lost. The successful grantsman is usually well rewarded, and thus, is one illustration of the esteem afforded a leader who can acquire resources.

Resource acquisition is a function similar to that of a corporation's sales force. Both obtain orders from users for future services. Resource acquisition at the research station differs from the work of the sales force, however, in that the users of information are often not the suppliers of funds. Since the research station obtains resources from several sources, the intermediate product of resource acquisition is critical, complicated, and itself a user of resources.

Technology

TECHNOLOGY is the means or process by which the intermediate and final products of the institution are produced. Each process used to produce an intermediate product or a particular package of final information should be as efficient and low cost as possible. Technology is seldom stagnant; thus, an institution must continuously attempt to keep its professional personnel abreast of both the scientific and institutional state of the arts. Research also contributes methodology; thereby an institution may develop technology to raise its own efficiency or effectiveness.

Clearly, attendance at professional meetings, sabbatical leaves, and inservice and staff training are all important to scientific methodology improvement. Perhaps more important is an attitude of trying to constantly improve accounting, linkage techniques, information distribution, reporting procedures, recruiting efforts, and so on and on, throughout the institutional system.

All seven intermediate products are first-level services produced directly as a result of utilizing inputs in organizing and operating the institution. These intermediate products are inventoried internally and recombined into final products before they are of value to the using society. But in order for these first-level services to be produced, resources must be available as system inputs.

SYSTEM INPUTS

INPUTS are resources of all kinds that enter into the research process. They are used in operating the research institution and are transformed into intermediate and final products. The most costly or valuable inputs are professional or scientific personnel, then technicians, graduate assistants, farms, herds, and current expense. These conventional inputs and all other inputs may be viewed as being of one of three types: flow inputs, capital stock, or growth stimulators.

Flow Inputs

FLOW inputs are those resources that must be used when available, usually in a continuous or seasonal manner. Flow inputs that feed into the system over time are usually quite readily identifiable. The three primary categories are (1) staff time, (2) services of buildings and land, and (3) the interest and cooperation of clients. Flow inputs cannot be stockpiled effectively. The particular mix of flow resources, as well as the total quantity available, influence the outputs of the station. While the mix of resources can be altered over time, some of the current flows of services may be of little value and

are difficult to use or convert into flows of more valuable inputs. Flow inputs are the most valuable of all station inputs, but some of them are almost always underutilized.

Stock Resources

STOCK resources are the inventory of valuable assets of the station, one class of which is institutional capital—both physical and human. Physical capital is traditional—buildings, farms, laboratories, equipment, herds, flocks, libraries, seeds, genetic germ plasm banks, and many other types of material. This stock, of course, can be drawn down or increased. The station manager, like the corporate executive, may be wise at times to convert his stock of physical resources into cash as a substitute for appropriations, thereby maintaining the flow of current services. At other times, flow resources may be diverted from producing current services to increasing the stock of valuable assets.

Human capital is the stock of intellectual capacity available among the institution's staff. It cannot be very systematically appraised or reported in the annual inventory. However, this stock resource is very easily drawn down or lost faster than it is replenished. Human capital can also be built up through investment in staff training, inservice learning, and time for reading and self-teaching.

The other two classes of stock resources—change propensity and opportunity—may be viewed as growth stimulators. They are probably a significant factor explaining variation in institutional development among research stations. Change propensity is a stimulator of growth. The staff's collective knowledge of, desire for, and acceptance of change and its cost seem to explain some of the differences in growth rates among experiment stations. If station staffs are willing to accept change, they can exploit more growth opportunities than if they resist change. Change propensity is difficult to measure, but is related to self confidence, willingness to take risks, and the desire to be socially responsive. Disagreement among the staff and leadership, for example, over which client groups, doctrine or program are important, will probably decrease the change propensity within an institution.

In addition to change propensity, internal and external opportunity for change is necessary to stimulate growth. Opportunities for growth and improvement differ widely among stations. If there are many opportunities to contribute to strongly held social goals, then external opportunity exists for growth. However, if the suppliers have no strong social goals to which research can significantly contribute, growth opportunity does not exist. When the return to society from allocating funds to nonresearch organizations is rapidly increasing, the competitive position of the station and its opportunity for growth are both diminished.

Growth may be inhibited by self-imposed, narrow-scope statements, which limit the institution to offering research services only in nongrowth areas. Opportunity for growth may be internally constrained by risk aversion or work preference of staff. In either case, the prospects for the institution's viability are not encouraging.

DYNAMIC DEVELOPMENT

OVER time, the set of stock resources of a successful developing institution will expand. As a result, a vigorous, viable research institution (a) becomes autocatalytic in nature, (b) gains more autonomy and respect within the society it serves, and (c) becomes accepted as a source of norms and innovations by the larger society. The dynamically developing research institution will become a prized and meaningful structure in the society it helped to modify and modernize. Consequently, adequate support by the larger society is to be expected. However, neither expansion of resources nor survival is likely to characterize an institution which persists in low-value expenditures. We cannot afford to ignore the information needs of well represented potential beneficiaries, even though the investigations required would be nontraditional. Increased research support is won by being able at the margin to contribute more to fund suppliers' goals than other competing agencies.

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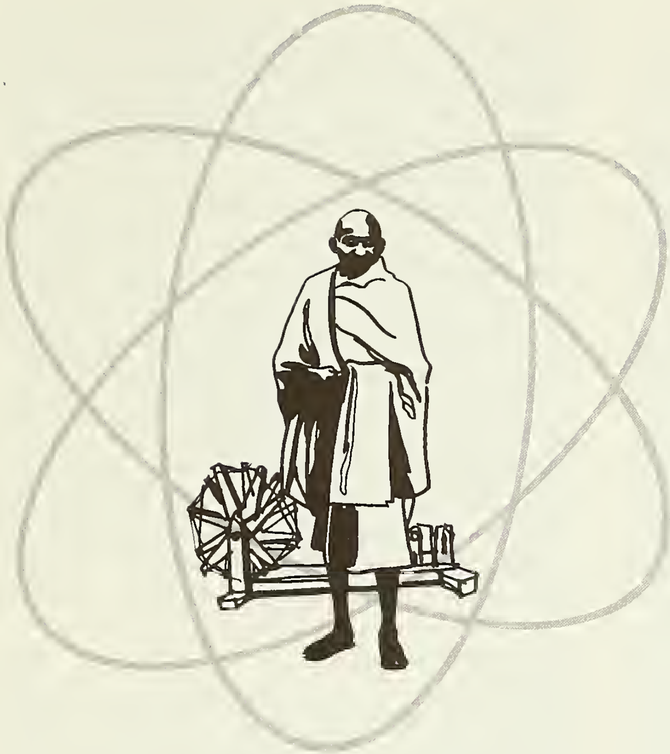


"The problem is how to try and preserve the experience and the visions of a higher life which have been perceived by prophetic men. Another great problem is how to utilize the wonders of science so that they are applied for the uplift of man and not merely for material things."

AGRICULTURE, SCIENCE AND HUMANITY

B. P. PAL

GREEN chlorophyll came before red blood; plants preceded animals on this earth of ours and the green leaf governs the economy of nature. The early history of man is shrouded in the mists of time, but the evolutionary record clearly delineates man's kinship with the animal world. Henry Bailey Stevens has speculated that man's ancestors, like the great apes, lived in the trees and subsisted on a diet of fruits, nuts, and tender leaves. But when prehistoric man descended to the ground he had to become a hunter to gain his daily food.

Agriculture and Food

THERE was a very long period of time before man, by a slow process of domestication of plants and animals, laid the foundations of a settled agriculture, so essential for the development of civilization. But the early history of agriculture, like that of man himself, is a matter of conjecture. Archaeologists, anthropologists, and others have studied the remains that are found at the ancient sites uncovered by excavations and propounded theories as to what must have been the conditions of human life in those bygone eras. Even about that well-loved flower, the

This article was adapted from the author's Gandhi Memorial Lecture delivered at the Raman Research Institute, Bangalore, Oct. 2, 1971. The original lecture was published in *Current Science*, India's fortnightly journal of research, Vol. 40, No. 20, Oct. 20, 1971, and the adaptation is published herewith through the kind permission of Editor A. S. Ganesan.

rose, Walter de la Mare has said:

> "Oh! no man knows
> Through what wild centuries
> Roves back the rose."

In most of our crop plants too, no one knows when they were first cultivated; quite often even the immediate ancestors of these types have disappeared, leaving scope for the writing of many doctoral theses on their supposed origins.

It is truly astonishing that early man was able to do such a remarkable job of plant improvement. As Edgar Anderson has pointed out, modern man, in the 5,000 years of recorded history, has not been able to add a single major crop to his list of domesticates! Thus in the New World, maize, sunflower, cucurbits including the gourd, two species of tobacco, three species of Phaseolus, the groundnut, the amaranth, and the quinoa had already become cultivated plants before the dawn of recorded history. Similarly, in the Old World, wheat, rice and a great many other economic plants including fruits and vegetables had been developed. It appears that, in the beginning, the tendency was to make multiple uses of plants rather than cultivate them for a single purpose as is often the case in our modern mass production agriculture.

Through the outstanding contributions of the Russian botanist, N.I. Vavilov, the importance of collecting and preserving as wide a range of germ plasm as possible of economic plants and their wild allies has come to be recognized. Vavilov's life work also indicated that there were some areas in the world in which as a result of favorable conditions, species and varieties of certain economic plants were found in unusually amazing abundance. These he regarded as centers of origin of our cultivated plants. There has been some tendency recently to question whether these were really the centers of origin or rather the centers of survival of genetically important variations. But whichever view is taken, there is no doubt that these natural gene pools are very important for the immediate and future work of the plant breeders, and everything possible must be done to collect and conserve them before valuable genes are lost forever.

While plants because of their possession of chlorophyll can, utilizing the energy of sunlight, create their own food, all animals and man either live on plants or on animals which again, in their turn, live on plants. To be in good health the human body requires to be in a state of efficiency; that is, not in mere passive existence but with the capability to resist disease and to meet other calls upon its energy. Food is a primary necessity and as the Japanese saying points out:

"Even Fuji is without beauty to one hungry and cold."

Mahatma Gandhi referred to the same fact in the following unforgettable words: "I may as well place before the dog over there the message of God as before those hungry millions who have no lustre in their eyes. . . . How am I to talk of God to the millions who have to go without two meals a day? To them God can only appear as bread and butter." In another significant sentence, on another occasion, he said: "To a people famishing and idle, the only acceptable form in which God can dare appear is work and promise of food as wages."

Food Population Problem

ONE of the great problems of the present world is that of food supply for the population of the world which is increasing at a terrifying pace. Although the developed countries are largely characterized by large farms and adequate resources with which they are able to produce enough food of the different kinds required, in the densely peopled underdeveloped countries, there is a continuous struggle to find the means of subsistence for huge populations. In most parts of tropical and subtropical Asia, the average farmer has a small holding—usually about 2 hectares—and from this little piece of land without any other resources he has to maintain a family of eight or nine or even more persons. Unless we can find the means of feeding the millions of human beings who already inhabit this earth, talk of other things becomes almost meaningless. Though one recognizes that man does not subsist by bread alone, yet unless the bread is there he cannot exist to partake of the finer things of life.

It is one of the tragic paradoxes of our time that while in some countries there is so much surplus agricultural production that food or other useful materials are burned or thrown away to maintain a high level of prices, or farmers are subsidised not to produce more agricultural products; in large parts of the world there is the most grimly severe undernutrition and malnutrition. In spite of the fact that

man is heir to so many centuries of civilization and so many great religions have preached the brotherhood of man and other qualities, yet those who have the opulence permit the unfortunate people of the poorer countries to starve. While there is money and extraordinary scientific resources to permit space explorations, such resources and such intensive scientific endeavors have not been available to remove the misery of the world.

Agriculture therefore has, as never before, a role of the utmost significance for the welfare of humanity. In the past, in many countries like ours, it occupied a lowly place in the scheme of things. Even among the sciences, agricultural science was considered to be a plebeian sort of science. Its votaries were not as well paid as the others and suffered from various disadvantages. Fortunately, in very recent years, some changes for the better have taken place. In this country there has been some reorganization of agricultural research and education, and already this has yielded results which have enabled us for the present to ward off the threat of famine and given us the confidence to face the future.

We must, however, take serious note of the fact that even with the best of efforts, after awhile there will not be sufficient food unless the rate of population increase is greatly slowed down, especially in the developing countries where the problem is most acute. The urge to reproduce is one of the fundamental characteristics of all living matter and in some forms of life the rate of multiplication is fantastic.

Safe Limits Exceeded

ACCORDING to Dr. S. Pradhan, "It has been calculated that the progeny of a single moth can cover the entire dry surface of the earth to a depth of 80 feet within a period of 1 year if all the progeny are allowed to live their normal life. This calculation is based on the assumption that a moth lays just 200 eggs and completes its life history in one month. Both these assumptions are quite normal for a large number of insect species while there are species of insect in which thousands of eggs are laid per female. Compared to this, the reproductive capacity of the human race is quite modest. But already in many countries, we have reached or even somewhat exceeded the safe limits for bringing land under the plough. If we encroach upon our precious forests and pasture lands, this may lead to dolorous results, changing even the climate of the country for the worse.

The developing countries have many handicaps to overcome. The soil in many of them is highly eroded and its content of major nutrients is exhausted because of centuries of exploitation. There are many other problems, but there is also tremendous potentiality. In a masterly summary, Dr. M. S. Swaminathan, in a paper prepared for a conference dealing with the role of nuclear techniques in agricultural research in developing countries, refers to "certain unusual possibilities awaiting exploitation" which are now in sight. These have opened up entirely new vistas for increasing the productivity of irrigated agriculture in the tropics and subtropics, which are endowed with abundant sunlight throughout the year, through the developments of scientific multiple and relay and cropping systems.

Through the introduction of genetic factors for photo- and thermo-insensitivity, most crop plants can be made to flower and fruit within a specific period, thereby eliminating or reducing their dependence on seasons and making the introduction of the concept of "productivity per day" possible. Considerable advances in water technology and water harvesting procedures have increased the productivity per unit of water and dry land farming is much more remunerative.

Developments in fertilizer technology and pest control procedures, coupled with the concept of appropriate plant types or architecture, have changed many old notions on the genetic ceilings to yield. This in turn has opened up new prospects for restructuring cropping systems so as to maximize the income from small holdings. Advances in postharvest technology have made income from agriculture (including horticulture and animal husbandry) more secure and stable. But most importantly, experience from developing countries, which have introduced a synergistic package of new practices in areas where agriculture had remained stagnant for a long time, has clearly revealed that the new technology can serve as a catalyst bringing about rapid change in the outlook of the farming community, provided the technology offers hope for making a substantial jump in yield and income.

But we need more than food. A modern society requires roads, railways, airfields, industrial com-

plexes, also schools, hospitals and other necessary amenities. But if we plan with sagacity, using science both to increase the productivity of agriculture and to slow down the birthrate of the human race, the problems of food supply and raw materials for trade and industry can be solved.

The Role of Science

SCIENCE is essentially a quest for truth. Modern science has developed to such a great extent, and at such a tremendous pace during the past few decades, that its results permeate every segment of our lives. Like a modern Prometheus, science has brought hundreds of things within the reach of man, helping many to live a life more complete with amenities and comforts than was possible before. Above all, science has made it possible for man to enjoy leisure. As long as man was dragged down by the drudgery of eking out his daily existence without the help of scientific tools, he had little time for anything else and leisure is necessary for man to think and to concern himself with the higher things of life. But even today there are millions of our fellow beings who do not have leisure. In fact, as pointed out by Bertrand Russell, "the idea that the poor should have leisure has always been shocking to the rich!" We have to see, with so much development in science, that all human beings have the requisite amount of leisure.

In this country between 70 to 80 percent of the population lives directly or indirectly by agriculture. It appears that, unlike what has happened in many advanced countries where the farming community has dwindled to a very low figure, in India this is not likely to happen on a large scale in the next couple of decades at any rate. The problem, therefore, is one of finding employment especially for the members of the farming families. It would be tragic if there is a large-scale exodus from the countryside to the cities which are already overcrowded.

The remedy seems to lie in a phased but rapid development of agro-industries, especially the small and medium ones, in the rural areas, taking care of course to see that problems of pollution, etc., are foreseen and avoided, and that the natural tranquillity and beauty of the countryside is preserved as much as possible. It is only industry which can give employment to very large numbers of people, but it is not necessary that all industry be located in the big cities. With the experience which is now available, and keeping in mind the agricultural transformation which has begun to take place, there seems to be a great opportunity for setting up a number of agro-industries specially selected for the needs of the various regions.

Although I have referred so far to the many benefits resulting from science, there are also undesirable effects from the wrong use of science. But if science is properly used, it is an invaluable tool not only for helping us to achieve greater agricultural production, but also to help us to do our work with the minimum of drudgery; it can also give us many ways to make our lives richer, fuller, more rewarding.

Problems of Humanity

THIS earth of ours, at her fairest, is beautiful, wonderful. Witness the serenity of the deep cobalt blue firmament on a fine day. And the shapes and forms of the everchanging clouds—dazzling white cumulus clouds piled high, one upon another, or the fleecy, softly moving, cirrus types. What wonderful colors are displayed in a sunset: here, rose and amethyst melt into gold and orange, while there, mauve and lilac tints change and transform themselves into yet other indescribable hues, and the deep blue of the upper heaven softens into cerulean and lemon as it approaches the horizon.

Or, behold the spiritually uplifting world of the Himalayas; mountain range succeeds mountain range until the eternally snowclad sentinels of the north of our land are reached. Who has not felt elevated, far above the affairs of the mundane world, in this realm of snowcapped peaks, fair valleys and forests of whispering pines and deodars? Then there is the wonder of flowers, of birds and butterflies, of rainbows, of palm-fringed golden beaches and starlit nights.

But nature can be terrible in some of her moods, such as volcanic eruptions, earthquakes, floods, typhoons, and cyclones, bringing death and destruction in their wake. We also know the term, "Nature, red in tooth and claw." Animals and birds prey upon each other and when we look closely we find a terrific struggle going on everywhere. Man is no exception; even after so many centuries of so-called civilization he is still engaged in bloody conflicts. There appears to be a crisis of character. Traditional values are fast changing and one does not feel that man is making progress in all directions.

How do we ensure the right use of science? As we have seen, science can give us many many things. But the pursuit of science should not be a dry academic or purely utilitarian undertaking. It should not lead to the state where someone had to declare:

"On the shore of intellect
I forgot how to fly."

Every discovery, according to David Sarnoff, "reveals more clearly the divine design of nature, remarkable harmony in all things, from the infinitesimal to the infinite. Physical processes and laws imply a Supreme Intellect." How can we plan science teaching so that the student develops not only a mastery of the physical laws of nature, but also a respect for and some understanding of the divine design in nature to which Sarnoff refers? How can we build up a race of people who, in the words of Tagore, would pray: "Make my life simple and straight, like a flute of reed for thee to fill with music"?

As I have implied earlier, the great advances in agriculture have aroused the hope and confidence that mankind can feed itself and yet maintain a certain balance of nature—but only if we think ahead and make the right decisions, including the laying down of a progressive economic policy. Most assuredly, science has a role to play in augmenting our resources of food and materials, in finding how to restrain the growth of populations to manageable proportions, and in giving us the blessings of leisure in which to enjoy the fruits of progress.

In spite of the astonishing discoveries in many fields—man has already walked on the moon five times—the greater part of humanity still suffers from lack of food, lack of clothing, lack of housing, lack of education, and lack of medical facilities. Above all, it seems to suffer from a diminution of the human spirit so that the spirit of contentment seems to be something that is vanishing more and more. What is it that we can do?

One of the great problems in building up and raising humanity to new heights is that while from time to time great leaders and great seers have arisen, there is no genetic mechanism for handing over their achievement to those human beings who follow them. Science has shown quite conclusively that normally acquired characteristics are not inherited. The experience of a lifetime can thus be lost. There is a saying in an Eastern country that "experience is a comb which nature gives to man after he is bald." The problem is how to try and preserve the experience and the visions of a higher life which have been perceived by prophetic men. Another great problem is how to utilize the wonders of science so that they are applied for the uplift of man and not merely for material things. How can we prevent science being misused to spread death and destruction and pollution of the environment?

The answer to both of these seems to lie in the creation of a system of education which would, first of all, try to create conditions under which latent talent would be nurtured and developed. We do have some talent search schemes for science, but they tap a pitifully small section of our vast population. Studies conducted a few years ago by a world authority on the subject indicated that intelligence and the capacity to produce geniuses is not the monopoly of any one human race.

Need to Identify Talent

BUT the well-being of a nation can well depend on the steps which it takes to discover those individuals who are gifted by nature but require the environment to bring out their special qualities. To take an example, India has done well in the

world of sports in certain games like tennis and cricket. But what is the proportion of school children in our country who get a chance to handle tennis rackets or cricket bats and balls, let alone receiving coaching from specialists? There must be many talented children who never receive the opportunity to show what they are capable of. The same applies to science and to other sectors.

In a country like ours, there is tremendous scope for identifying at an early age and educating those who could contribute in a substantial way to the future prosperity of the country. The second and most important objective of the system of education must be to teach science in such a way that those who practice it are conscious of the beneficial directions in which they should try to advance, and the harmful directions which should at all costs be avoided. In fact, such a system of education is needed not only for the scientists, but for all others who are likely to be concerned with the use of the products of science—whether it is for industry or for building up national defense systems. While we cannot do without science, we can certainly try to see that education is restructured to create a society in which the higher values of life will prevail.

This is a difficult task but not an impossible one, because as Maurice Frydman has said, "The great achievements of mankind can be always traced to some great and simple intuition, some overwhelming inspiration, taking hold of one man's heart and mind till it becomes for him the most important thing in the world." Even a few devoted persons can in due course of time spread their message in such a way that the bread of life will be leavened.

How do we start doing this? How do we make a blueprint for a new educational system based on science? It seems to me that there is no alternative but to assign this task to a small group of very carefully selected individuals—not those who have hobbyhorses from which they refuse to dismount, but those who are knowledgeable, who are filled with dedication to the cause of education, and who are willing to give and receive in discussion. A large conference, lost in the mediocrity of averages, would not serve the purpose. And once a really gifted group of individuals can lay down the guidelines, these should be considered at the highest level of government, and implemented with utmost vigor and speed.

If we can do this and develop a race of mankind which will utilize the fruits of science while suppressing to the maximum extent possible the animal traits which we have inherited from our animal ancestry, there may yet be hope for *Homo sapiens*. Nature's gifts to the developing countries are natural resources, the most important among them being the human resources. At present, human energy often lies idle and underdeveloped. To activate and develop resources in the developing countries, proper education in all aspects of development is of utmost importance.

Finally, we should ponder upon what is our purpose in life on this earth of ours. Is it only to hunt for food, to reproduce the species, and to sleep? If that were so, man would be no higher in the scheme of things than animals, which also do the same things, sometimes with more grace than we. But if we consciously strive to use science and education to achieve life which is more imbued with the qualities of kindness and mercy, with vision, wisdom and energy, with more of truly human feeling and awe of the grand design of nature, we would be carrying out to some extent the high ideals laid before us by the Mahatma.

A Research Opportunity for Agricultural Science

LESTER HANKIN

ONE of our most pressing environmental concerns is the ever-mounting quantity of solid waste material being generated by households and industry. The problem appears more critical in large urban centers because a large portion of the waste material is placed in landfill. However, it also is an "agricultural" problem since a considerable portion of the solid wastes originate on farms.

The day is rapidly ending when we can consider solid wastes agricultural or otherwise as waste products only. Instead we will have to treat them as raw materials to be utilized in other processes to form useful products. Who is in a better position to suggest uses for these "new" agricultural materials than agriculturally and biologically concerned scientists?

Agricultural scientists are in a unique position to provide solutions on what to do with some of the solid wastes. In what follows, I draw from my own research and that of my colleagues an example of how agricultural research can be utilized to attack a major problem of our urban society.

The Soft-rot Problem

MY colleague, Dr. Milton Zucker, who was in the Department of Plant Pathology and Botany at the Connecticut Station, and I had been investigating some *Erwinia* and *Pseudomonas* species for about 2 years. These bacteria are soft-rot pathogens on various crops and stored tissue, a problem of vital concern to farmers and packers. They destroy plant tissue by producing macerating enzymes, the primary one perhaps being pectate lyase which attacks the pectin molecule and degrades it to the level of uronides. The pectin thus degraded is no longer able to sustain the integrity of the cells within the tissue and the tissue collapses. We were interested in learning about the biochemistry of the

enzyme systems involved in the soft-rot or maceration process.

Our studies included the mechanisms by which potato tissue, under some conditions, was able to withstand attack by the soft-rot organisms. The conditions under which pectate lyase was produced were also examined. One of our goals was to find a way to protect plants and stored plant tissue from attack by the organism. How the plant protected itself was also studied. We were able to make some contribution toward solving these problems.

Additionally, we discovered the conditions in which the enzyme was produced and the requirements for its production. The characteristics of induction of the enzymic activity were also studied. Induction of the enzyme by the organism was accomplished readily in a medium containing pectin together with an extract from potato. In many instances, 100 times more enzyme activity was produced than under normal growth conditions. The amount of activity produced per bacterial cell was also greatly increased by the induction process. This finding provided useful information on how the organism was able to produce the enzyme so that a protective mechanism for plants might be evolved. Also, the inductive process probably stimulated the production of other enzymes by the organism, such as proteolytic systems. This turned out to be useful later in the actual degradation of garbage which contained some protein material. We believe that our investigations contributed to the knowledge of enzyme physiology and the mechanism of enzyme action, and provided some applications toward purely agricultural uses.

Experiments with Garbage

WHILE this research was underway, the problem of solid waste disposal and utilization came to the forefront. The available data indicated that about 12 percent of all household trash was composed mainly of food debris. Probably a large portion consists of unusable or nonedible plant tissue. Our research experience with both the organism and the enzymes made us confident that the macerating enzymes derived from phytopathogenic bacteria would degrade household garbage.

Our approach was to take a system detrimental to our crops and turn it around to make a beneficial system that would solve an environmental problem.

Laboratory experiments supported this idea. Pectate lyase for these experiments was derived from the culture fluid of *Erwinia carotovora*. Household garbage was chopped, a small amount of water added, and mixed with a smaller amount of enzyme (as culture fluid). The ratio used was about equal parts of garbage to water (w/v). About 1 to 2 ml of culture fluid per 100 gm of garbage-water mixture was used as the enzyme source. Subsequent experiments showed that lesser amounts of water could be used: 3:1 (w/v).

Within 4 hours after addition of enzyme to the garbage, the garbage was visibly degraded and within 18 hours almost completely degraded. Other experiments confirmed that the degree of maceration was dependent on the amount of plant tissue in the garbage; the more plant tissue, the higher the percentage of degradation. We called the degraded material "liquefied garbage."

Degradation or maceration of garbage in the laboratory is one thing, but the problems of utilization or disposal remained. We felt that it was incumbent on us to at least suggest potential uses for the treated material. I believe that those who do laboratory experiments should attempt to offer possible applied uses for their findings.

Other Possible Uses

AFTER completing the laboratory portion of our studies, we proposed several possible uses for liquefied garbage. One was to use it as an animal feed. It was not so long ago that garbage was fed to hogs; but this became uneconomical when most States required that the garbage be cooked or boiled in order to destroy the *Trichinella* organism. Since the liquefied garbage can be pumped it is amenable to heat treatment by a continuous process. We suggest that it could be heat-treated by utilizing a high-temperature short-time pasteurization unit and then either spray- or drum-dried as is now done for the manufacture of milk powder. The dried material might then be used as animal feed.

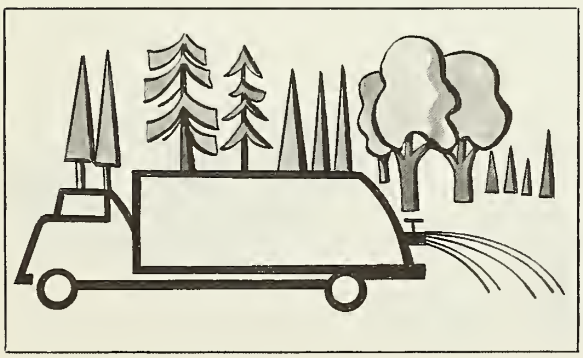
Another proposal was to return the dried, degraded garbage for reuse in the areas from where it came. Much of the garbage from edible organic solids in the Northeast comes from farm areas in the Western States. Returning this material would provide a dual benefit. It becomes another form of agricultural produce rather than a waste product.

At the same time the garbage would be removed from heavily populated areas which are having disposal problems.

Data are not as yet available as to whether this can be done economically. However, if it is not economically feasible today, it may be tomorrow, and even if not economically feasible it may have to be done anyway.

We also examined the possibility of using degraded garbage as a soil amendment or fertilizer. Liquefied garbage is in a sense "instant compost." What the enzyme does, theoretically, takes place in the soil through the action of soil micro-organisms. However, a much longer time would be needed. Liquefied garbage, as we prepared it, ranged from 5–10 percent total solids with a nitrogen content of about 0.15 percent (based on the total degraded material) and lesser amounts of phosphorous and potassium. Approximately one-sixth of the total nitrogen is readily available to the plant. Thus, liquefied garbage applied at the rate of 1 acre-inch provides 300 pounds of total nitrogen of which 50 pounds would be immediately available.

Field experiments to test the usefulness of degraded garbage for plants were conducted with Dr. George Stephens, my colleague in the Department of Ecology and Climatology. The garbage used was obtained from local supermarkets and consisted almost entirely of discarded produce, trimmings, and material no longer saleable. This garbage was chopped with a compost shredder and about half-ton quantities were treated with pectate lyase. The enzyme was prepared in the laboratory from culture fluid of *Erwinia carotovora*. The bacterial cells were killed before using the enzyme fluid to degrade garbage. The ratio of garbage to water added was about 3:1 (w/w) with about 2–3 gallons of culture fluid being used. The incubation time was 24 hours.



Yield Increases Obtained

THE liquefied garbage was applied to both crops and trees. Application to crops such as corn, beets, carrots, beans, and tomatoes were made at the rate of 1 and 2 acre-inches. Control plots received a chemical fertilizer based on the amount of immediately available nitrogen in the liquefied garbage. Excellent results were generally obtained after we learned to control some of the problems. Seeds planted and covered immediately with 1 inch of liquefied garbage either did not germinate, or were unable to penetrate the dried film. However, if the liquified garbage was allowed to dry for 1 day and the seeds planted through a slit, then they germinated and grew well. Also, tomato plants receiving 1 inch of freshly made liquefied garbage died; but when planted through the semi-dried film they showed no ill-effects and grew better than did the control plants. If a half inch or less of liquefied garbage was applied, no harm resulted to tomato plants.

When the detrimental effects discussed above were controlled, yields from plots treated with liquefied garbage were higher than in control plots for all the crops that were planted. Part of the increase came because the liquefied garbage formed a mulch over the soil surface which suppressed weed growth dramatically and conserved soil moisture. However, part probably was due to the fact that the control plots received only the nutrients initially applied, while the liquefied garbage provided additional nutrients during the growth period.

The liquefied garbage was also applied to tree plots at rates up to 3 acre-inches. This amount is equivalent to as much as 240 tons of raw garbage per acre. The trees took up and utilized the nitrogen as determined by analysis of leaves, and no detrimental effects were seen. Whether such large additions of nutrients can be made on a sustained basis is questionable since trees are limited in their capacity to take up nutrients. Any excess might appear in the ground water.

Forests can provide substantial areas for the disposal of biodegradable wastes. For Connecticut we calculate that 6,300 tons of garbage (i.e. 12 per-

cent of the total household waste) are produced each week. If this garbage were liquefied with pectate lyase and placed in the forest at the 2 acre-inch rate, 44 acres would be needed each week, or less than 2,500 acres per year. Even in populous Connecticut this would not constitute an unreasonable utilization of the forest. Forests are particularly valuable since they can store the nutrients they take up over a long period of time. Eventually when the trees are harvested some of the waste will be reclaimed as lumber.

It is also important to consider other possibilities. If liquefied garbage could not be used on crops during a portion of the growth period or spread on the land or in a forest during the winter months, other methods of disposal might be needed. One possibility is to feed it into a secondary sewage treatment system, although this method does not seem as desirable as the others.

In experiments made in collaboration with William Glover of the Connecticut State Department of Health, liquefied garbage was fed into a laboratory model of a secondary sewage system. Levels of liquefied garbage normally encountered in a municipality were not detrimental to the system. In fact, indications are that moderate levels (up to 10 percent) of liquefied garbage enhanced the growth of the microorganisms present in the aerobic system and thus better degradation of the sewage. At a higher level (25 percent), the system failed. However, this level was reached by adding the garbage on a batch basis. Under actual operating conditions, neither this high a level of garbage nor batch feed would likely be used.

In this phase of the experiments, we were able to add some knowledge useful to the operation of a secondary sewage treatment system. We learned how, at least experimentally, to prevent scum formation, a common problem which can occur in secondary treatment systems. Such information has already been put to use in alleviating scum formation in two municipal treatment plants.

This is another example of how knowledge gained through agricultural research benefited another discipline—in this case, sanitary engineering science.

Wider Role for Agricultural Research

LIQUEFIED garbage is not, of course, the final answer to the problem of garbage disposal or utilization. Many degradative processes are known in agriculture which could be put to use in helping to solve contemporary problems in waste disposal or utilization. For example, information gained in research on the fermentation of tobacco may be useful in evolving a better understanding of composting. Eventually such information, gained in agricultural research, might be applied to other aerobic degradation processes such as in secondary sewage treatment systems. The reader is referred to the most recent review on the subject of degradation of organic matter by my colleague Dr. Raymond Poincelot.

Our experiments with liquefied garbage point to many potentialities. I hope that they will stimulate others to consider these and other lines, such as the use of enzymes and other biological tools to convert waste into useful materials. On a broader scale, our experiments suggest that many possibilities exist for wider use of knowledge already gained in agricultural research. Agricultural science and scientists can play a vital role, not only in research on waste utilization, but in many other nonagricultural areas as well.

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NEW FACILITIES AT THE SOUTHERN FOREST FIRE LABORATORY

NEW construction at the Southeastern Forest Experiment Station's Southern Forest Fire Laboratory at Macon, Ga., will add more than 20,000 square feet and provide facilities for more than 20 additional scientists and support personnel. Renovation in the present building will improve the scientific capabilities of a huge windtunnel and multistoried combustion room.

The original laboratory was built in 1959 by the Georgia Forest Research Council and staffed by Forest Service scientists from the Southeastern Forest Experiment Station. The laboratory is a product of State-Federal cooperation on the part of the Georgia Forestry Commission, the Georgia Forest Research Council, and the Forest Service.

The South has the Nation's most critical forest fire problem. About 60 percent of all wildfires in the United States occur in this 13-State area, annually burning over at least three times as much forest land as in any other region. In spite of improved technology and aggressive control agencies, the 1960's saw little overall reduction in either the number of wildfires or the acreage burned.

The occasional catastrophic fire—the blowup fire that becomes unmanageable—causes about 90 percent of the damage to our natural resources. Consequently, one of the urgent research missions at the laboratory is aimed at identifying the combination of fuel and weather conditions that trigger these blowups. Scientists believe that it will be possible to predict the probable occurrence of blowups, specify appropriate action to prevent their buildup, and develop improved control techniques.

Research into prescription burning also will be expanded. Robert W. Cooper, who heads up the smoke management research and development program at the laboratory, points out that prescribed burning is one of the most effective tools of fire prevention and control, as well as of forest management. Yet, there is public concern that open, free-burning fires create undesirable accumulations of smoke and may contribute to atmospheric contamination. Mr. Cooper said the expanded program would be designed to acquire and disseminate technology regarding the formation, dispersal, precipitation, modification, and manipulation of wood smoke; its chemical and physical composition; the development of methods of predicting patterns of smoke concentration; and means of reducing harmful emissions.

Mr. Cooper envisioned the 1970's as a decade during which great strides can be made in the improved use of fire as a tool of forest management, in the application of smoke management guidelines, in the development of other treatments of forest debris with minimal environmental impact, and in improved prevention and control measures for the problem wildfire.

Economic Importance of MASTITIS RESEARCH in the United States

EDWIN I. PILCHARD

THIRTY years ago, when sulfonamide drugs and pencillin introduced the age of "wonder drugs," optimism was widespread that mastitis would someday be eliminated as the most serious disease affecting the dairy industry. Research which has spanned an even longer period to the present day has gradually increased the accuracy of mastitis diagnosis, provided better methods for its prevention, and greatly broadened the armamentarium of drugs and antibiotics for its treatment. Yet according to some agricultural officials, annual losses due to bovine mastitis are estimated at $500 million, and ultimate eradication seems a distant goal indeed. This cost is equivalent to 8 percent of the 1970 farm value of $6,523 million for milk and milk products. Nonmilitary consumer expenditures for milk and milk products during the same period were $15,500 million.

Only one common form of mastitis, caused by *Streptococcus agalactiae,* is thought to be eradicable with scientific knowledge currently available. Diligent application of some available control methods can perhaps decrease the prevalence of other forms of the disease. But many researchable problems remain to be solved before the whole complex problem of bovine mastitis can be effectively dealt with. A review of recent research suggests a need to launch a more incisive and forthright attack on the mastitis problem than is now going on. Careful analysis of a profile of current research on mastitis, such as the one presented here, can provide useful guidelines for rational allocation of research resources. Such guidelines should form an important part of the decision base for research resource allocations, bringing more investigative talent to bear where problem solving results are most likely to be produced.

The Mastitis Complex

BRIEFLY described, mastitis is an inflammation (*itis,* Gr.) of the mammary gland (*mastos,* Gr.) of different causes, intensities, durations, and aftereffects. It is a complex disease which commonly results in some degree of permanent impairment of milk-secreting capacity. Milk from the affected cows is unmarketable, and additional economic damage results from wasted labor, feed, barn space, antibiotics, antiseptics, laboratory services, veterinary services, and regulatory administrative costs.

Public health hazards from mastitis have been relatively insignificant in the United States, or so at least they have seemed. However, the ready availability and frequently unwise use of antibiotics

in attempted treatment or control has raised concern that a contribution is being made to the growing problem of antibiotic resistant infection and antibiotic allergy among humans.

Both the economic efficiency of the dairy industry and consumer health would benefit if mastitis were eradicated. Scientific knowledge available for the solution of many other problems of disease and food production would also increase through the research which is to make mastitis eradication feasible. The potential economic benefits seem certain and substantial. If bovine mastitis were no longer present in the United States, the total annual benefit would exceed $540 million by 1980. One factor contributing to this total gain is an estimated average increase of 366 pounds of marketable milk per cow. Another is longer productive lifetime of cows and elimination of their death due to mastitis, for an estimated annual saving of $84.5 million. Also, the combined annual costs of over-the-counter drugs and veterinary services would decrease approximately $67.5 million.

In perspective, cash losses attributed to bovine mastitis are an important economic burden on the agricultural industry. When one considers that dairy products yield 22 percent of the $29.6 billion received for all livestock products, and that these, in turn, constitute 60 percent of the $49.2 billion received for all agricultural commodities, the loss due to mastitis seems proportionally large.

Recent Status and Changes

MOST of the publicly supported research on bovine mastitis in the United States is documented in the Current Research Information System (CRIS) of the U.S. Department of Agriculture. Research project information for 1968 and 1970 was selected for discussion because these were respectively the earliest and latest year in which records were complete. Economic estimates were obtained from the U.S. Department of Agriculture and the U.S. Department of Commerce.

Farm income from milk and dairy products increased 18 percent during the 2-year period ending January 1, 1971, for a total of $6.5 billion—even though during the same period the numbers of dairy cows and heifers dropped 5 percent, and mastitis continued to take its toll. Mastitis research funds increased 35 percent during this same period, for a total of $1.6 million—or an amount equivalent to 0.01 percent of cash income from dairy products (table 1).

Most of the increase in total mastitis research funds from 1968 to 1970 was due to so-called "in-house" research of the Agricultural Research Service (ARS). The ARS fund allocations approximately doubled and both the number of scientist man-years and total number of research projects increased approximately one-half (table 1). These changes appear desirably proportional to an increase in the value of dairy products. Also the average ARS scientist-man-year (SMY) was supported by approximately $60,000 in 1968, and by $80,000 in 1970, an increase which exceeds the current 5.5 percent annual inflationary increase in the cost of doing research.

TABLE 1.—*Status of mastitis research in the United States, 1968 and 1970*

Year	Research expenditures			Scientist-man-years			Projects		
	SAES	ARS	Total	SAES	ARS	Total	SAES	ARS	Total
	Thousand dollars			*SMY's*			*Number*		
1968	822	386	1,208	17.7	6.4	24.1	36	6	42
1970	880	700	1,580	14.9	9.8	24.7	40	9	49
Change	+58	+314	+372	−2.8	+3.4	+0.6	+4	+3	+7
Percent change	+7	+81	+30	−16	+53	+2.5	+11	+50	+17

During the same period, funds expended for mastitis research in the State agricultural experiment stations (SAES) increased 7 percent and number of projects increased 11 percent, but at the same time, SMY's dropped 16 percent. The average SMY was supported by $47,000 in 1968 and by $59,000 in 1970, exceeding the inflationary increase in cost of doing research previously mentioned. This proportional increase should permit more effective use of research manpower.

An average of from $50,000 to $60,000 may be considered as minimal adequate support for a full-time scientist in animal disease research at the State stations. A minimum of $90,000, however, is estimated to be required for the support of one SMY in the Federal animal disease laboratories. This figure is considered comparable to the minimum estimated requirement at SAES because many ancillary costs which are available without charge to a research project at a State university are charged directly to a project account in the Federal system.

Regional distribution of mastitis research in the SAES's is shown in table 2. State and regional priorities tend to be reflected in the research of the State stations largely because approximately 80 percent of the research funds available there are non-Fed-

TABLE 2.—*U.S. regional data on farm income from dairy products, total dairy cows and heifers 2-yrs. old and older kept for milk, and status of mastitis research, 1968 and 1970*

Regions [1]		Farm income from dairy	Dairy cows and heifers	Research expenditures		Scientist-man-years		Research projects		
				SAES	ARS[2]	SAES	ARS[2]	SAES	ARS[2]	Total
		Million dollars	*Thousands*	*Thousand dollars*		*SMY's*		*Number*		
NE	1968	1,308	2,892	216	137	5.0	2.4	7	1	8
	1970	1,538	2,785	205	317	3.8	2.5	7	3	10
	Change	+230	−107	−11	......	−1.2	......	0	......	+2
	Percent	+18	−3.7	−5	......	−24.0	......	0	......	+40
S	1968	979	3,008	213	1	4.9	NI[3]	11	1	12
	1970	1,188	2,829	228	5	4.1	NI	13	1	14
	Change	+209	−179	+15	......	−0.8	......	+2	......	+2
	Percent	+21	−5.7	+7	......	−16.8	......	+18	......	+17
NC	1968	2,454	7,017	182	238	3.6	4.0	9	3	12
	1970	2,804	6,550	301	367	4.2	7.3	11	4	15
	Change	+450	−467	+119	......	+0.6	......	+2	......	+3
	Percent	+18	−6.6	+61	......	+17.0	......	+22	......	+25
W	1968	789	1,745	211	11	4.2	NI	9	1	10
	1970	992	1,711	146	11	2.8	NI	9	1	10
	Change	+203	−34	−65	......	−1.4	......	0	......	0
	Percent	+26	−2.0	−31	......	−33.0	......	0	......	0

[1] Northeastern, Southern, North Central, Western.
[2] ARS mastitis research projects are not necessarily regional projects.
[3] NI: not indicated.

eral. In contrast, research in Federal laboratories of ARS tends to reflect national priorities and therefore can be considered separately in an evaluation of relative proportionality of geographical distribution. Most of the mastitis research of ARS is located in the Federal laboratories at Beltsville, Md. (Animal Science Research Division), and at Ames, Iowa (National Animal Disease Laboratory, Veterinary Science Research Division).

North Central Leads

THE greatest regional total of SAES expenditures and manpower allocations for mastitis research during 1970 was in the North Central (NC) region, followed in descending order of magnitude by the Southern (S) region, Northeastern (NE) region, and Western (W) region. The funds in the NC, NE, and W regions are respectively equivalent to 0.01 percent of the cash receipts for dairy products in the region. The expenditures in the S region are comparable to 0.02 percent of the cash receipts for that region. These allocations seem relatively low. Of course, there would need to be a value judgment on potential effectiveness of the research in solving the problems which cause mastitis losses in order to adequately justify proportional increases in these funds.

The substantial increases between 1968 and 1970 in the NC region of 61 percent in research expenditures and 17 percent in SMY's seem desirable when judged by the great importance of dairying in this region. Each SMY in mastitis research here was proportional to $670 million in cash receipts for dairy products in the region during 1970. Cash receipts for dairy products for each SMY in mastitis research in the other regions followed in descending order: $410 million for NE, $355 million for W, and $291 million for S. The ranking is similar for mastitis research funds expended by region. With regard to both SMY and research expenditures, the greatest allocations to mastitis research in proportion to the regional cash receipts for dairy products were in the W region during 1968, and in the S region during 1970.

Significant changes have occurred between 1968 and 1970 in the distribution of total mastitis research effort between SAES and ARS (fig. 1). During 1968 the SAES contributed 68 percent of the funds, 74 percent of the SMY's and 86 percent of all research projects in bovine mastitis in the United States. In 1970, the SAES's contributed nearly the same proportion of projects, 84 percent as before, but the funds there declined to 54 percent of total funds and SMY's declined to 60 percent. Unless there was a qualitative improvement in the research, these changes denote an overall diffusion of effort at SAES, and a potentially lower rate of problem-solving achievement.

Mastitis Research Objectives

ALL project descriptions for 1968 and 1970 were analyzed to determine the primary objective in each. Objective categories which included two or more projects are shown in the upper section of table 3. Most of the projects had other objectives in addition to a primary one. The lower section of table 3 shows categories which included four or more projects with the respective objectives.

Some major changes are apparent for the 2 years. Three projects were added to the 1968 total of eight in which various management or animal caretaking procedures were studied for their possible effects on or correlations with the incidence of naturally occurring mastitis. There was also a notable increase in the numbers of projects on pathogenesis, which attempt to describe how various kinds of mastitis are initiated and developed.

Also showing increases were studies on (1) treatment of mastitis in nonlactating (dry) mammary glands, (2) the recently proposed procedure of dipping the teats in disinfectant solution immediately after milking for the prevention of possible transmission of mastitis organisms, and (3) the various aspects of immunological resistance to mastitis. The numbers of projects on enumerating somatic cells (white blood cells) in milk as a possible means to detect unhealthy mammary glands, on the improvement of other diagnostic methods, on the heritability of mastitis, and on the evaluation of the California (CMT) and Wisconsin mastitis tests (WMT) changed slightly or remained unchanged.

It is tempting to judge that some unnecessary duplication of effort is illustrated in table 3. Indeed, the fact that the CMT procedure has been widely used and evaluated since its introduction in 1957, suggests prolonged duplication of effort. However, it is very likely that the test is not being evaluated as announced in the project description, but rather

TABLE 3.—*Research project emphasis in bovine mastitis, United States, 1968 and 1970*

Primary objective of project	SAES		USDA	
	1968	1970	1968	1970
	Number		*Number*	
Management	7	8	1	3
Diagnosis	4	6	3	3
Evaluation of cell count	8	6	1	2
Description of pathogenesis	3	5	1	2
Treating dry cows	1	7	0	0
Immunity	5	4	0	0
Dipping teats after milking	3	2	0	0
Evaluation of heritability	2	2	0	0
Objective included in project				
Evaluation of cell count	15	12	2	5
Treating dry cows	6	12	0	0
Evaluation of California mastitis test	11	10	0	1
Dipping teats after milking	4	9	1	2
Immunity	6	11	0	0
Evaluation of Wisconsin mastitis test	6	4	0	0

is being used as a standardized experimental method to follow the course of the disease. In those projects evaluating somatic cell count, however, only three or four different procedures are being investigated, so that some unnecessary duplication of effort is a likely possibility. Here, as with other categorized examples shown, there is ample justification to carefully examine all related research in progress before deciding to initiate, continue, or abandon a researchable idea.

Inferences and Suggestions

SOME facts, estimates, and analyses presented in this paper suggest there is a fairly balanced distribution of relatively modest commitments of public funds for mastitis research among the geographical regions of the United States. A reasonable balance is also apparent among the States within these regions, when the data were examined before being summarized. However, the continuation of many different studies on very similar aspects of bovine mastitis seems a situation of questionable merit which deserves further scrutiny.

The rationale for allocating publicly supported research resources to bovine mastitis, or to other subjects, should be based on (a) accurate establishment of the significant economic and public health importance of the problem and (b) clearly described experimental hypotheses and researchable ideas dealing with inadequately understood or obscure problems.

In assigning priorities to mastitis research programs, research leaders might do well to keep in

mind at least three worthy areas for investigation that were designated by the 1968 joint task force on a National Program of Research on Dairy: (1) development of more economical methods for diagnosing specific pathogenic organisms causing udder infections, (2) development of economical sanitation procedures for the prevention of spread of udder infections, and (3) the characterization of mechanisms of resistance in cows and development of methods for increasing the action of these mechanisms in preventing udder infections. Although we may have to admit that complete conquest of bovine mastitis is unattainable, it seems logical to assume that a more incisive and forthright planning effort on the above three areas of study could materially reduce the continuing high incidence of losses.

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MOOSE EXTEND RANGE

ALTHOUGH moose numbers have declined in North America, the Shiras, or Yellowstone, subspecies has been increasing in number and extending its range to the south. First sighted in Yellowstone Park in the late 1960's, the Shiras are now in northern Utah and Colorado. For example, numbers increased fivefold on the northern slope of the Uinta Mountains from 1966 to 1971, reaching a total of 371.

Because of potential damage to the habitat from overbrowsing, a research project to study various aspects of the food habits of moose was initiated in 1969. It is sponsored jointly by the Utah Cooperative Wildlife Research Unit at Utah State University and the Utah Division of Fish and Game.

VANISHING MUCKLANDS

SOIL subsidence has been a problem in the muckland of Florida's rich Everglades agricultural section ever since the area was drained about 60 years ago. Soils in the Everglades are basically a layer of organic matter over limestone rock strata and range from about 2 feet to 10 feet in depth. At one location at the Agricultural Research and Education Center, Belle Glade, the soil has dropped 4½ feet over a 47-year period. Projections indicate the average soil depth at the Center will be reduced another foot by 1980.

Soil subsidence is initiated by drainage. Biochemical oxidation by soil microorganisms is the most important factor. Others include shrinkage from drying, compaction, burning, and wind erosion. A continuing research program in soil subsidence is being carried on at the Center.

MORE VETERINARIANS NEEDED

A need for more than 40,000 active veterinarians in 1980, 15,000 more than in 1970, is projected by the committee on veterinary medical research and education of the National Research Council. The estimate assumes some influx of paraprofessionals into the field. The committee, chaired by former U.S. Surgeon General Luther L. Terry, projected the 1980 supply of veterinarians at 38,000 including those who are retired or inactive. The estimates are contained in the committee's report, *New Horizons for Veterinary Medicine,* published this year by the National Academy of Sciences.

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U. S. GOVERNMENT PRINTING OFFICE : 1972 O - 470 - 720

AGRICULTURAL SCIENCE REVIEW is a critical review journal designed to provide a common point of understanding among agricultural scientists by publishing authoritative commentary on the current state of agricultural research. *Review* does not publish primary research reports. Yearly subscription rate is $1.25, domestic; $1.50, foreign. Single copies are 35 cents. Subscription orders should be sent to the Superintendent of Documents, Government Printing Office, Washington, D.C. 20402.